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Improving the Global Ionospheric Predictions of f_oF_2

B. S. DANDEKAR

10 June 1976

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IONOSPHERIC PHYSICS DIVISION PROJECT 7663
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AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

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Chief Scientist

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Using the method of Rush and Gibbs (1973), weighted means of observed values have been used to update the global predictions of f_oF_2, which are based on monthly median values derived from the Institute of Telecommunications Sciences model (1969). This procedure improved the predictions for magnetically quiet periods, for times near minimum of the solar cycle phase, and for the equinoctial months. Furthermore, a closer grid of ionosonde stations resulted in reducing the error in the f_oF_2 prediction. For the method

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20. Abstract (Continued)

of Rush and Gibbs (1973) to be operationally successful in global predictions of f_oF_2, however, a closer grid of ionosondes than is presently available is needed.

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Preface

The author wishes to thank Dr. Charles Rush and Major Wilson Edwards, USAF, for their interest in the work.

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Illustrations

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Improving the Global Ionospheric Predictions of f_oF_2

1. INTRODUCTION

At present long term ionospheric predictions can be routinely obtained from theoretical models[1] and statistical models.[2-5] Due to insufficient knowledge of both, the number of parameters and their accurate values needed in the theoretical models, these models are useful for ionospheric prediction purposes only in a gross sense. Statistical models based on analysis of ionospheric observations deal with a limited number of parameters such as plasma frequency, height of

(Received for publication 8 June 1976)

1. Nisbet, J.S. (1971) On the construction and use of a simple ionospheric model, Radio Science 6:437-464.
2. Jones, W.B. and Gallet, R.M. (1962) Representation of diurnal and geographic variations of ionospheric data by numerical methods, ITU Tellecomm. J. 29:129-149.
3. Lucas, D.L. and Haydon, G.W. (1966) Predicting Statistical Performance Indices for High Frequency Ionospheric Tele-communication Systems, Tech. Rpt ITSA-1, Environmental Science Service Administration.
4. Barghausen, A.F., Finney, J.W., Proctor, L.L., Schultz, L.D. (1969) Predicting Long-Term Operational Parameters of High Frequency Sky-Wave Telecommunications Systems, Tech. Rpt ERL 110-ITS-78 ESSA Research Laboratories, Institute for Telecommunication Sciences.
5. Headrick, J.H., Thomason, J.F., Lucas, D.L., McCammon, S.R., Hanson, R.A., and Lloyd, J.S. (1971) Virtual Path Tracing for HF Radar Including an Ionospheric Model, Naval Research Laboratory Memorandum Rpt 226.

maximum electron density, and their latitudinal, longitudinal, diurnal, and seasonal variation. The Institute for Telecommunication Sciences model (ITS), documented by Barghausen et al,[4] is based on such a statistical approach and is the most commonly used HF propagation prediction model. The ITS model provides monthly median predictions of HF propagation conditions. However, Air Force operational systems generally require ionospheric and propagation predictions on a shorter time scale, that is, a few hours in advance. Under these circumstances, the hour-to-hour and day-to-day variability displayed by the ionosphere becomes of paramount importance. Rush et al[6] have shown that f_oF_2, the critical frequency of the layer, is the most dominant parameter in determining HF propagation conditions for modes reflected by the F_2 layer. Furthermore, Rush and Gibbs[7] have shown that, for a given location, predictions based on recent f_oF_2 observations afford an improvement over the monthly median predictions for predicting day-to-day variability.

The purpose of this report is to determine the magnitude of improvement in the global predictions of f_oF_2 achieved by updating the monthly median predictions with the weighted means of f_oF_2 observations.[7] In the next section the data and analysis used in this investigation are described. In the third section the results are summarized and in the last section the implications of these results are discussed.

2. DATA AND ANALYSIS

Observations of f_oF_2 from 32 ionosonde stations from the European-Asian sector in the northern hemisphere were used in this study. Table 1 contains a list of these stations along with their geographic and geomagnetic coordinates and their time zones. These stations were selected on the basis of availability of ionospheric data for the calendar years 1960, 1964, and 1968.

The mapping procedure of Miller and Gibbs[8] and of Edwards et al[9] was used for obtaining global maps of f_oF_2 predictions. These predictions were based on the

6. Rush, C.M., Miller, D., and Gibbs, J. (1974) The relative daily variability of f_oF_2 and h_mF_2 and their implications for HF radio propagation, Radio Science 9:749-756.

7. Rush, C.M. and Gibbs, J. (1973) Predicting the Day-to-Day Variability of the Midlatitude Ionosphere for Application to HF Propagation Predictions, AFSG No. 168, AFCRL-TR-73-0335.

8. Miller, D.C. and Gibbs, J. (1974) Ionospheric Analysis and Ionospheric Modelling, AFCRL-TR-74-0364.

9. Edwards, R.W., Rush, C.M., and Miller, M.D. (1975) Studies on the Development of an Automated Objective Ionospheric Mapping Technique, AFCRL-TR-75-0124.

Table 1. List of Ionosonde Stations Used in Present Investigation

Stations	WDC* Code	Geographic Lat. N	Geographic Long.	Geomagnetic Lat.	Geomagnetic Long.	Time Zone GMT	Remarks
Akita	539	39.7	140.1	29.3	205.4	9	U_4, L_4**
Alma-Ata	343	43.2	76.9	33.2	150.8	5	U_1, L_3
Ashkhabad	237	37.9	58.3	30.3	133.4	3	U_4, L_3
Beograd	145	44.8	20.5	43.7	100.9	1	U_4, L_1
Freiburg	048	48.1	7.6	49.5	90.0	0	U_1, L_2
Gorky	156	56.1	44.3	50.2	126.9	2	U_4, L_1
Irkutsk	352	52.5	104.0	40.9	174.4	6	U_1, L_3
Juliusruh	055	54.6	13.4	54.5	99.0	0	U_4, L_2
Kiruna	167	67.8	20.4	65.2	116.0	1	U_1, L_1
Leningrad	160	60.0	30.7	56.2	117.6	2	U_2, L_1
Lindau	050	51.6	10.1	52.3	94.1	0	U_3, L_2
Lycksele	164	64.7	18.8	62.7	111.4	1	U_3, L_1
Miedzesyn	152	52.2	21.2	50.7	104.8	1	U_4, L_1
Moscow	155	55.5	37.3	50.8	120.7	2	U_1, L_1
Murmansk	168	69.0	33.0	64.0	126.8	2	U_1, L_1
Nurmijarvi	159	60.5	24.6	57.8	112.8	1	U_1, L_1
Okinawa	426	26.3	127.8	15.1	195.6	8	U_1, L_4
Providenya	664	64.4	186.6	59.5	235.5	-11	U_2
Pruhonice	052	50.0	14.6	49.9	97.6	0	U_4, L_2
Roma	041	41.8	12.5	42.5	92.1	0	U_3, L_2
Rostov	149	47.2	39.7	42.4	119.4	2	U_2, L_1
Salekhard	266	66.5	66.5	57.2	149.0	4	U_2, L_3
Slough	051	51.5	359.4	54.4	83.5	0	U_1, L_2
Sodankyla	166	67.4	26.6	63.7	120.4	1	U_1, L_1
Sverdlovsk	256	56.7	61.0	48.3	140.8	4	U_2, L_3
Taipei	424	25.0	121.2	113.5	189.5	8	U_1, L_4
Tehran	236	35.7	51.4	29.2	126.6	3	U_3, L_3
Tokyo	535	35.7	139.5	25.3	205.4	9	U_1, L_4
Uppsala	158	59.8	17.6	58.5	106.2	1	U_4, L_1
Wakkanai	545	45.4	141.7	35.1	206.0	9	U_1, L_4
Yakutsk	462	62.0	129.7	50.8	193.8	9	U_3, L_4
Yamagawa	431	31.2	130.6	20.1	197.8	8	U_3, L_4

*WDC – World Data Center

**Letters U and L are for uniform and longitudinal geographic coverage, and subscript presents the group

monthly median values of f_oF_2.[2] The monthly median global predictions were updated by observations of f_oF_2 in the following way. A first guess monthly median value of f_oF_2 is computed using the monthly median model values. This first-guess value is then updated in four iterative steps by the weighted mean of the f_oF_2 observations. The updating and iteration procedure has been described by Edwards et al.[9] Rush and Gibbs[7] tried 3-, 5-, and 7-day weighted means for f_oF_2 predictions only for locations at which f_oF_2 observations were available. As a compromise between improved accuracy and the need for the consequent length of the data base, they recommend an updating by 5-day weighted means for prediction. Accordingly the prediction value of f_oF_2 for a given station is computed from the formula,

$$\text{weighted mean prediction of } f_oF_2 = \frac{\sum_{i=1}^{m} (m - i + 1)\, D_{-i}}{\sum_{i=1}^{m} i},$$

where m is the number of days used in computing the weighted mean, and D_{-i} is the value of the f_oF_2 on the ith day preceding the prediction day. In the present analysis, 6- day weighted means were readily available and therefore these values were used. The results of this study can be directly related to employing a 5-day weighted mean prediction since in most cases there is less than a 7-percent difference between the 5- and 6-day weighted means. Such small changes in prediction values do not produce any significant change in the final results.

One of the purposes of the present study was to determine the magnitude of improvement in the prediction of f_oF_2, using the updating procedure of Rush and Gibbs[7] compared with the monthly median predictions. Also investigated was the extent to which the improvement is dependent upon diurnal and seasonal variations of f_oF_2, upon magnetically quiet and disturbed periods, and upon the solar cycle phase.

In Table 2 the dates for which f_oF_2 predictions were made are listed. Data observed on these dates were used for measuring the error in prediction. For the prediction, f_oF_2 values computed from the monthly median and from the updating of f_oF_2, as suggested by Rush and Gibbs,[7] were used for the days preceding those listed in Table 2. The difference between the observation and prediction is a measure of the error.

Table 2. Dates for Which Data Are Used in the Analysis

Magnetically Quiet Days								
Year	**Month**	**Date**	**Year**	**Month**	**Date**	**Year**	**Month**	**Date**
1960	Mar	21	1964	Mar	2	1968	Mar	7
		22			19			8
		23			28			9
	Jun	11		Jun	3		Jun	21
		12			5			24
		16			6			25
	Sep	16		Sep	13		Sep	25
		20			14			26
		21			15			27
	Dec	4		Dec	11		Dec	2
		11			12			14
		14			31			15
Magnetically Disturbed Days								
Year	**Month**	**Date**	**Year**	**Month**	**Date**	**Year**	**Month**	**Date**
1960	Mar	11	1964	Mar	4	1968	Mar	14
		16			22			24
		31			30			30
	Jun	4		Jun	10		Jun	10
		27			20			11
		30			25			12
	Sep	4		Sep	22		Sep	8
		24			28			13
		30			30			23
	Dec	2		Dec	13		Dec	3
		15			16			5
		27			19			25

Rush and Miller,[10] Miller and Gibbs,[8] and Edwards et al[9] have described in detail a procedure for the synoptic mapping of f_oF_2 over a uniform grid with separation of 10^o in latitude and 15^o in longitude. Initially the value of f_oF_2 for each grid point is computed from the ITS monthly median prediction program. Then, from a given number of locations, the value of f_oF_2 for each grid point is computed using predetermined weighting factors. These weighting factors are functions of

10. Rush, C.M. and Miller, D. (1973) A Three-Dimensional Ionospheric Model Using Observed Ionospheric Parameters, AFCRL-TR-73-0566, ERP, No. 455.

N-S and E-W separations of locations, and are based on a previous correlation analysis.[11] Predictions of f_oF_2 at a given location are determined by interpolation from the four-cornered grid enclosing that location. The error in the prediction of f_oF_2 is then computed as a root-mean-square value of the difference between observations and predictions for the locations used in the study.

An operational system may have a limited number of randomly distributed ionosonde stations that provide observations from which predicted maps of f_oF_2 can be made. It is necessary to know the accuracy with which predictions can be obtained for these observing locations, as well as for other locations for which f_oF_2 observations are not available. This situation was simulated in this study by dividing the ionosonde stations of Table 1 into four groups. The first group was treated as an observing and prediction set supporting an operational system. Remaining groups were treated as verification sets of nonobserving locations for which f_oF_2 predictions were needed. These f_oF_2 predictions were obtained from Group 1 stations. For each group, stations were selected to provide a uniform coverage of the geographic region. In the last column in Table 1 these groups are identified.

For the dates given in Table 2, predicted maps of f_oF_2 using the weighted mean prediction were generated at hourly intervals, using only stations of the first group. The root-mean-square error was determined for each group from predictions and observations of f_oF_2. As all groups have uniform geographic coverage, the results should be nonbiased. *Therefore the results of Groups 2 to 4* were added together. As a measure of improvement in the prediction by updating over that from the monthly median predictions, differences were computed between the respective errors of these predictions.

For studying the improvement in the prediction of f_oF_2 with respect to the diurnal, seasonal, magnetic, and solar dependence of f_oF_2, prediction errors and their frequency of occurrence were determined by dividing the data (for the dates of Table 2) into the respective categories.

3. RESULTS

In Figure 1 Section A, an example is presented of a prediction map of f_oF_2 for 1200 GMT for 25 September 1968. The prediction is from the monthly median model. The f_oF_2 contours are labeled in MHz. For the map, the geographic range of latitude is 10^oN to 70^oN, and the geographic range of longitude is 80^o to 240^o. In Section B a map generated from observations at the Group 1 stations for the

11. Rush, C.M. (1972) Improvements in Ionospheric Forecasting Capability, ERP, No. 387, AFCRL-TR-72-0138.

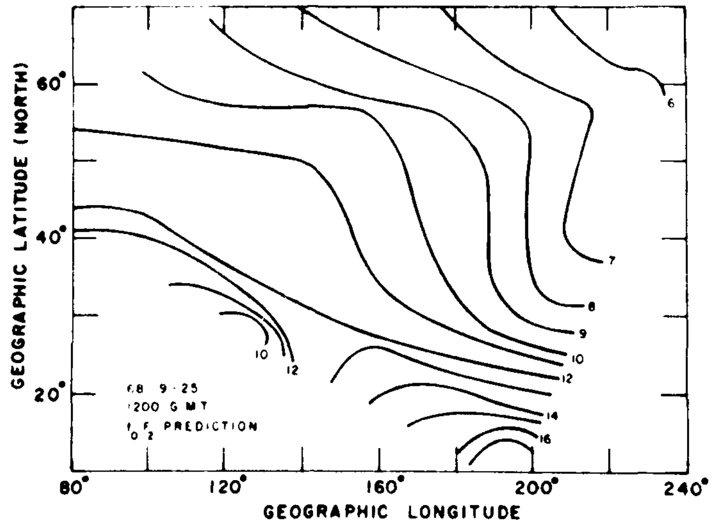

Figure 1A. An Example of a Prediction Map of f_oF_2 for 1200 GMT for 25 September 1968

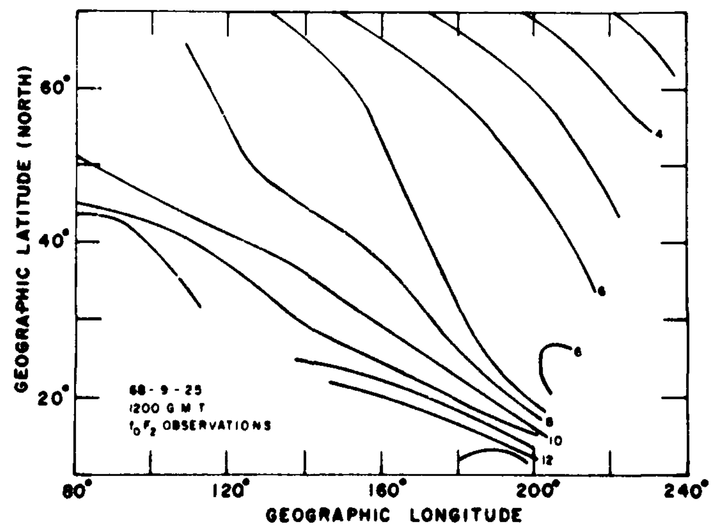

Figure 1B. Contours from Actual Observations of f_oF_2 from Ionosonde Stations for 1200 GMT for 25 September 1968

same time is presented. In the prediction map of Section A, f_oF_2 values range from 17 MHz near the equator to 6 MHz at northern latitudes, whereas the corresponding values in Section B range from 13 to 3 MHz (actual observations). For this time the root-mean-square error in prediction is 3 MHz.

Figure 2 is a graph showing an example of hourly errors in the mapping of f_oF_2 for both the monthly median prediction, and the updated monthly median values by the 5-day weighted means.[7] Section A is for 11 June 1968 and Section B is for 25 September 1968. Continuous lines are for the monthly median predictions and the dashed lines are for the updated predictions. In each section the bottom graph presents the first group, supporting an operational system, and the upper graphs present the remaining 3 verification groups. Note that the updated prediction is much better than the monthly median prediction for 25 September 1968, but is not useful for 11 June 1968. As shown in the figure neither procedure is superior for routine predictions at all times.

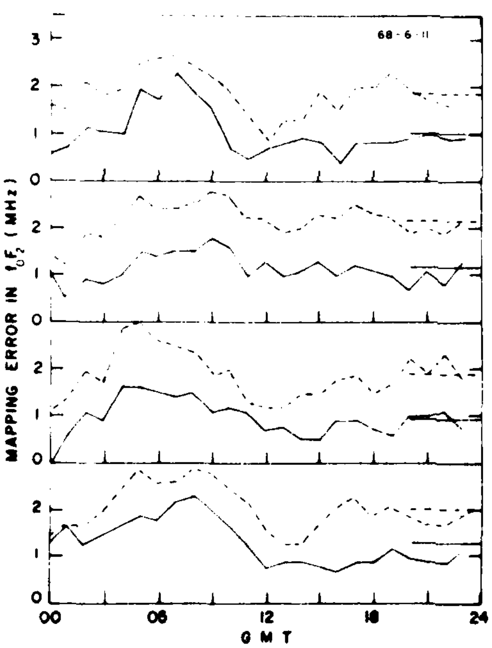

Figure 2A. Hourly RMS Errors in f_oF_2 Mapping for Both the Monthly Median Predictions (solid lines) and the Updated Predictions (dashed lines) for 11 June 1968

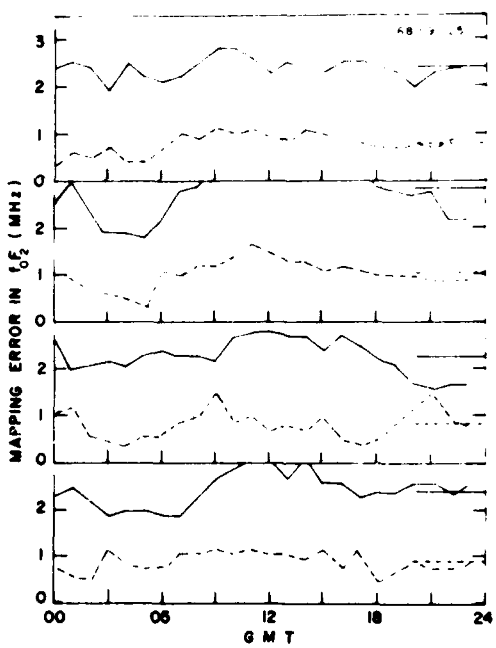

Figure 2B. Hourly RMS Errors in f_oF_2 Mapping for Both the Monthly Median Predictions (solid lines) and the Updated Predictions (dashed lines) for 25 September 1968

In Table 3A is presented the percent frequency of occurrence of improvement in the f_oF_2 predictions due to the monthly medians and due to the updating of the monthly medians. In the first three columns are listed the categories under which dates from Table 2 were grouped. The columns are year, month, and magnetic conditions, respectively. The improvement in the prediction of f_oF_2 is measured as a difference between corresponding errors for the respective procedures. The table is further refined by comparing the magnitude of improvement in the intervals ≥ 0, ≥ 0.3, ≥ 0.5 MHz. As explained before, Group 1 is used for prediction and the other groups are used for verification. Columns 4 and 5 list the number of cases available for hourly comparisons for prediction and verification, respectively. The percent frequency of occurrence of improvement for each procedure for the intervals ≥ 0, ≥ 0.3, ≥ 0.5 MHz is listed in columns 6 to 17. The average improvement in the magnitude of the predicted value of f_oF_2 using the updating, compared with that of the monthly median for prediction (Group 1) and verification (remaining groups), is listed in the last two columns.

In Table 3A we see that, for all days in Table 2, results from the updating are better than those from the monthly medians, for 71 percent of the time for prediction, and for 62 percent of time for verification. This percentage decreases rapidly as improvement of better than 0.3 and 0.5 MHz is sought. On the whole the improvement is 0.2 MHz in prediction and 0.1 MHz in verification.

When all data are divided into two groups, magnetically quiet and magnetically disturbed, the updated predictions look promising for the quiet periods, and are still as good as the monthly median predictions for the disturbed periods. The data were also grouped according to the calendar years. The solar activity was maximum in 1957 and 1968, and minimum in 1964. It is seen that in 1960, near the period of maximum solar activity, both methods yield comparable errors. It should be noted further that the magnetic activity in 1964, though descending from its peak of 1957, was stronger than the magnetic activity in 1968, for the dates chosen in this study. For 1968, the updating is better than the monthly medians 70 percent of the time for both prediction and verification, with an improvement in f_oF_2 mapping by 0.35 and 0.3 MHz, respectively.

When the data for each calendar year are divided in magnetically quiet and magnetically disturbed groups, it is found that neither of the procedures is better than the other for 1960, for either magnetic group. In 1968, for the magnetically quiet periods, the updating offers a significant improvement over the monthly median prediction for about 80 percent of the time, with an improvement in f_oF_2 of 0.6 and 0.45 MHz for prediction and verification, respectively. For all years during magnetically disturbed periods, only Group 1 prediction is improved by updating, compared with the monthly median predictions.

Table 3A. Frequency of Errors in Mapping f_oF_2 and Improvement in the Errors Gained by Using Updating Procedure vs the Monthly Median Predictions

Year	Month	Magnetic Conditions	No. of Cases for Prediction	No. of Cases for Verification	≥0 MHz Prediction MUWM	≥0 MHz Prediction Mon. Med.	≥0 MHz Verification MUWM	≥0 MHz Verification Mon. Med.	≥0.3 MHz Prediction MUWM	≥0.3 MHz Prediction Mon. Med.	≥0.3 MHz Verification MUWM	≥0.3 MHz Verification Mon. Med.	≥0.5 MHz Prediction MUWM	≥0.5 MHz Prediction Mon. Med.	≥0.5 MHz Verification MUWM	≥0.5 MHz Verification Mon. Med.	Magnitude of Improvement by MUWM* over Mon. Med. for (in MHz) Prediction	Magnitude of Improvement by MUWM* over Mon. Med. for (in MHz) Verification
All	All	Both	1728	5184	71	29	62	38	38	9	29	15	24	4	18	10	0.2	0.1
"	"	Quiet	864	2592	76	24	68	32	38	5	31	10	25	2	18	5	0.3	0.15
"	"	Disturbed	"	"	66	34	57	43	38	13	28	21	23	6	18	14	0.15	0.0
1960	"	Both	576	1728	60	40	50	50	33	14	22	28	19	7	13	18	0.1	-0.1
1964	"	"	"	"	78	22	66	34	29	3	18	6	14	1	6	2	0.15	0.05
1968	"	"	"	"	74	26	72	28	52	10	48	14	39	6	35	9	0.35	0.3
1960	"	Quiet	288	864	60	40	55	45	26	10	21	21	13	5	10	13	0.05	-0.05
1964	"	"	"	"	84	16	71	29	28	1	18	3	13	1	6	1	0.2	0.05
1968	"	"	"	"	83	17	79	21	58	3	52	6	48	2	38	3	0.6	0.45
1960	"	Disturbed	"	"	60	40	45	55	40	17	22	33	25	9	16	33	0.2	-0.1
1964	"	"	"	"	72	28	61	39	30	14	17	9	15	1	7	3	0.15	0.0
1968	"	"	"	"	65	35	64	36	45	17	44	21	30	10	32	15	0.2	0.15
All	Mar	Both	432	1296	68	32	61	39	38	10	31	21	26	4	22	13	0.3	0.1
"	Jun	"	"	"	61	39	53	47	20	13	16	20	12	7	7	14	0.05	-0.05
"	Sep	"	"	"	81	19	72	28	53	6	41	11	34	3	27	6	0.4	0.25
"	Dec	"	"	"	73	27	63	37	40	7	29	11	25	3	16	5	0.2	0.1
"	Mar	Quiet	216	648	75	25	65	35	41	5	35	17	29	1	26	10	0.4	0.2
"	Jun	"	"	"	74	26	69	31	18	3	17	7	6	2	2	4	0.05	0.0
"	Sep	"	"	"	83	27	81	19	59	5	47	5	44	2	32	2	0.5	0.4
"	Dec	"	"	"	70	30	58	42	32	7	23	13	19	3	12	5	0.15	0.05
"	Mar	Disturbed	"	"	61	39	57	43	35	16	27	25	22	6	18	17	0.2	0.0
"	Jun	"	"	"	49	51	37	63	23	22	15	33	17	13	13	24	-0.05	-.15
"	Sep	"	"	"	78	22	64	36	46	7	35	17	24	3	22	10	0.3	0.15
"	Dec	"	"	"	75	25	68	32	49	6	35	9	31	4	21	4	0.25	0.15

*MUWM - Monthly Medians Updated by Weighted Means

Since f_oF_2 shows a strong seasonal variation, it is expected that the accuracy of either prediction may display seasonal dependencies. It is seen that in Table 3A, in the equinoctial months of March and September, the updating yields better results compared with the monthly median predictions. For the solstitial months of June and December, there is no essential difference between the two procedures. The improvement in the magnitude of f_oF_2 on an hourly basis was also studied. The diurnal dependence of the prediction error is presented in Figure 3; Section A is an example of prediction and Section B of verification. The rows present magnetically quiet and magnetically disturbed periods for the years 1960, 1964, 1968. Overall, the updating is in general better than the monthly medians for both prediction and verification. Though the updating is better for the prediction groups, it does not offer any significant improvement to verification groups.

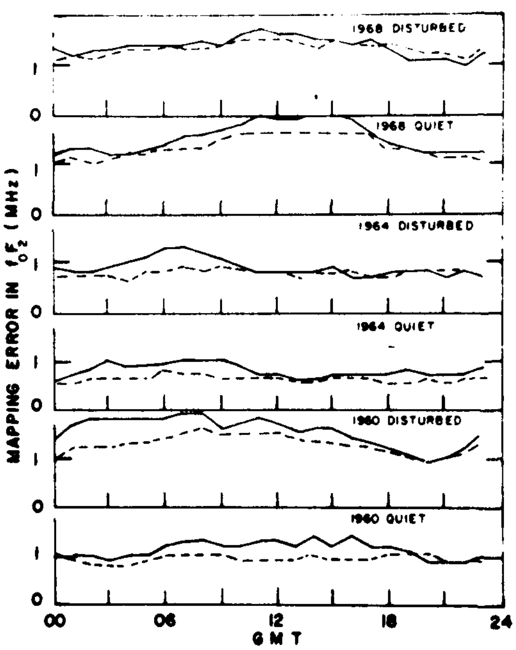

Figure 3A. The Diurnal Dependence of the Prediction Error (Prediction)

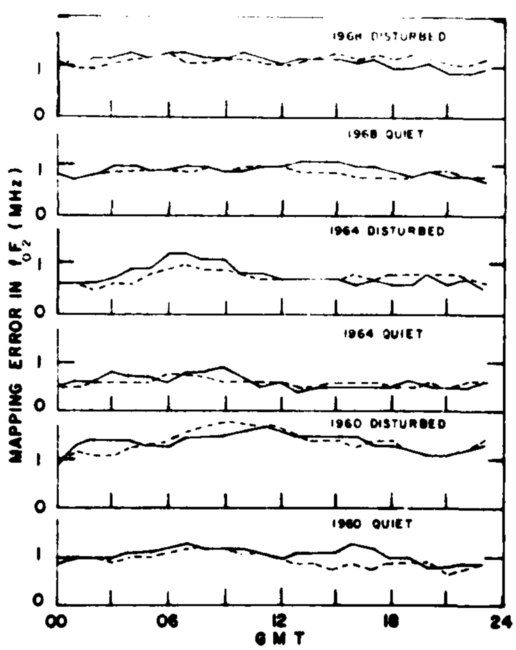

Figure 3B. The Diurnal Dependence of the Prediction Error(Verification)

Figure 4 is similar to Figure 3, as it is an illustration of the diurnal dependence for the equinoctial months of March and September. Again, for this period the updating shows significant improvement for both prediction and verification groups.

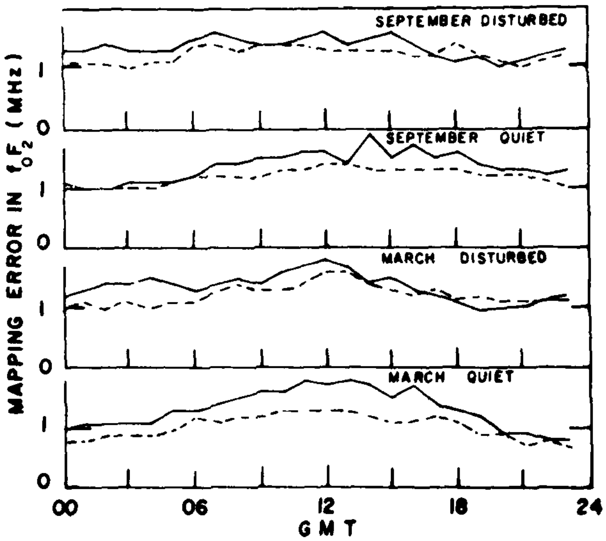

Figure 4A. The Diurnal Dependence for the Equinoctial Months of March and September (Prediction)

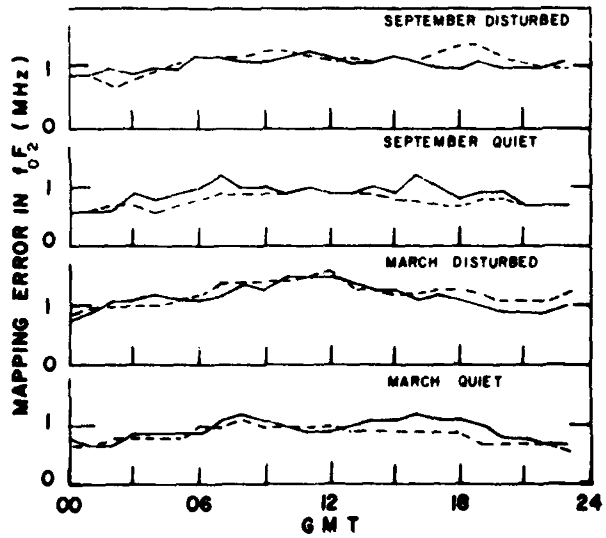

Figure 4B. The Diurnal Dependence for the Equinoctial Months of March and September (Verification)

4. DISCUSSION

We note that, in general, the updated predictions show an improvement over that of the monthly medians, in reducing the error in the prediction of f_oF_2. Both the magnitude of the error and the frequency of occurrence of improvement are significant during (1) magnetically quiet periods, (2) the minimum of the solar cycle phase, and (3) equinoctial periods. Also, the updated prediction is never worse than the monthly medians, except during the solstitial period of June for the northern hemisphere. Therefore, before deciding on the use of updating routine operations, the following questions must be addressed: (1) How significant is the improvement afforded by the updating in terms of routine operation, and (2) What are the limitations? These two questions are considered together.

In the process of mapping f_oF_2 predictions, observations from every station contribute to every point of the f_oF_2 map to a varying degree depending on the separation between the observing point and the mapping point. Rush[10] studied autocorrelation of various F-layer parameters for a few ionosonde stations. He finds that for a given station the autocorrelation of $N_mF_2(f_oF_2)$ falls to 0.7 after 2 to 3 hours during magnetically quiet conditions and after 1 to 2 hours during magnetically disturbed conditions. Thus, in general, the persistence of f_oF_2 can be expected to last for about 2 hours at a given location. Considering the rotation of the earth this could also be interpreted as a persistence of f_oF_2 over a separation range of 1500 km except for the transition regions of sunrise and sunset. Indeed, Rush[10] has found that the magnitude of covariation of f_oF_2 at two locations depends upon the separation between the locations. He has shown that this spatial dependence is important (correlation coeff. 0.8) up to separations of 750 km along N-S, and up to separations of 1500 km along E-W directions for ionosonde stations in the midlatitude region. The smaller separation of dependency distance along N-S could be due to the geomagnetic dependence of f_oF_2.

In the uniform geographic coverage case discussed above, which covered the European-Asian sector, the extreme separations amongst ionosonde stations, both in distance and time zone, are quite large. Further, in the uniform geographic coverage case, where an ionosonde station in each verification group is selected to represent geographically a corresponding one in the prediction group, it is not possible to assess the effect of geographic separation and difference in local time between the ionosonde stations on the error in the mapping of f_oF_2. This difficulty can be overcome by dividing the ionosonde stations in Table 1 into four groups, in intervals along longitudes. For determining the effect of station separation and difference in local time between the ionosonde stations, it is better to designate the group of ionosonde stations at one end of longitude intervals as the prediction group and the successive groups as the verification group. But, for assuring a best

possible prediction of the f_oF_2 map, the group containing the largest number of the ionosonde stations was designated as the prediction group and the remaining were designated as the verification groups. These groups are listed in the last column of Table 1. As before, Group 1 was used for prediction, and Groups 2, 3, 4 were used for verification. The time zones of Groups 2, 3, 4 differ from the time zone of Group 1 by -1.5, +2.5, and +7 hours, respectively.

For determining the effect of distance and local time separation amongst ionosonde stations on the error in prediction and verification of f_oF_2, data (in Table 2) grouped according to longitude were analyzed only for the calendar year 1968. For 9 March 1968, Figure 5A and 5B is a comparison of errors in the mapping of f_oF_2 for the sets of prediction and verification for two different distributions of ionosonde stations, uniform geographic coverage (described above), and grouped according to longitude. The error averaged for the day is shown on the right-hand side for each group.

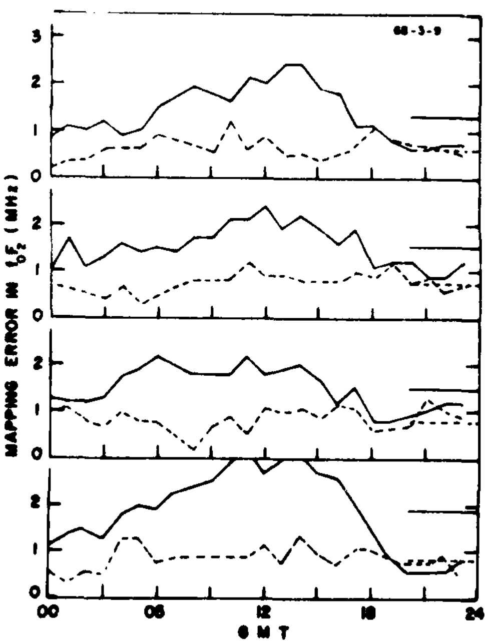

Figure 5A. Similar to Figure 2, Using Updating Stations Distributed Uniformly Over the Grid (9 March 1968)

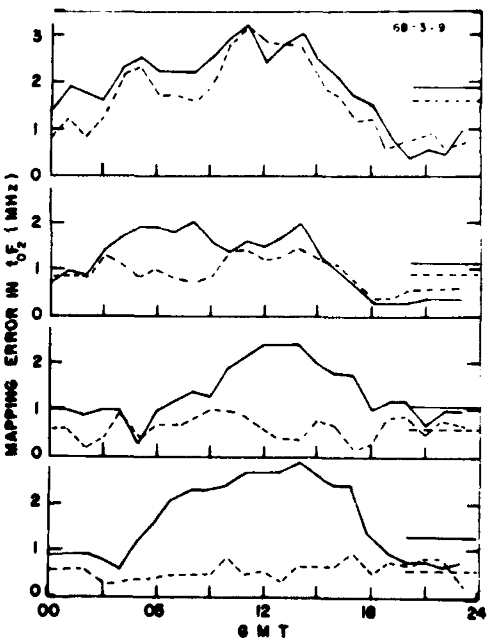

Figure 5B. Results for the Same Day for the Stations Grouped According to Longitude

In prediction-verification sets, one would normally expect small errors in prediction (Group 1 stations) as compared with those in verification (Group 2 to 4 stations). In Figure 5A, the results are shown using updating stations distributed uniformly over the grid (Table 1, Column 8). The magnitudes of errors for both prediction and verification happen to show no significant difference, but the degree of improvement in the prediction set is considerably greater. The point to be noted in Figure 5A is that the error for all the verification groups is of the same order of magnitude. This should be expected as the individual verification groups as well as the prediction group, in uniform geographic coverage case, are not biased as regards distance separations and local time differences amongst ionosonde stations.

In Figure 5B results for the same day for the stations grouped according to longitude are presented. The important point to be noted for Figure 5B is that the errors for verification Groups 1 and 2 are smaller and comparable to those for the prediction group. This is due to the fact that these verification groups are separated from the prediction group by small local time differences of -1.5 and +2.5 hours, respectively. In Figure 5B, for verification Group 3 (top section) with a separation of +7 hours from the prediction group, the mapping error is significantly larger than that for prediction. Results in Figure 5B indicate that predictions, using updating procedure, are good over a time range of about 2 to 3 hours. Considering the rotation of the earth, the range of distance for good predictions is about 1500 km.

In addition to considering the separation of the prediction and verification groups, separation of stations within a group was considered. In the case of the prediction groups of Figures 5A and 5B (bottom sections), the mapping error for the groups along longitudes is significantly reduced from that for the uniform geographic coverage case. This improvement in the mapping error in the former case may be due to the smaller separations both in distance and time of the ionosonde stations.

This is further illustrated by summarizing the results of the analysis of the 1968 data in Table 3B. This table is similar to Table 3A. Comparing the results for 1968 from Tables 3A and 3B we see that the updating offers a significant improvement over the monthly medians, in terms of percent time and the magnitude of reduction in the error of f_oF_2 for prediction (Group 1), and verification (Groups 2 and 3 only), during magnetically quiet periods, and also during the equinoctial months of March and September. However, the updating does not offer any improvement over the monthly median prediction for Group 4 and for the solstitial month of June. The tabulated results indicate that the improvement in error depends upon the spatial and temporal separation between ionosonde stations used for the prediction and verification of the f_oF_2 maps.

Table 3B. A Summary of the Results of the Analysis of the 1968 Data

Year	Month	Magnetic Conditions	No. of Cases for		Percent Cases of Improvement in f_oF_2 Mapping for Magnitude of												Magnitude of Improvement by MUWM* over Mon. Med. for (in MHz)		Group No.
					≥ 0 MHz				>0.3 MHz				>0.5 MHz						
			Prediction	Verification	Prediction		Verification		Prediction		Verification		Prediction		Verification		Prediction	Verification	
					MUWM	Mon. Med.	MUWM	Mon. Med.	MUWM	Mon. Med.	MUWM	Mon. Med.	MUWM	Mon. Med.	MUWM	Mon. Med.			
1968	All	Both	576	576	72	28	62	38	50	14	41	18	36	10	31	14	0.3	0.2	2
"	"	"	"	"	"	"	68	32	"	"	40	12	"	"	30	8	"	0.25	3
"	"	"	"	"	"	"	57	43	"		36	23	"	"	27	14	"	0.0	4
"	"	Quiet	288	288	81	19	82	18	54	8	70	7	38	5	64	5	0.5	0.25	2
"	"	"	"	"	"	"	85	15	"	"	70	4	"	"	65	2	"	0.3	3
"	"	"	"	"	"	"	63	37	"	"	38	12	"	"	28	5	"	0.1	4
"	"	Disturbed	"	"	63	37	80	20	45	19	71	11	34	14	66	9	0.15	0.1	2
"	"	"	"	"	"	"	83	17	"	"	70	8	"	"	65	6	"	0.2	3
"	"	"	"	"	"	"	51	49	"	"	34	34	"	"	26	21	"	-0.1	4
"	March	Both	144	144	75	25	72	28	56	8	60	10	43	7	44	5	0.6	0.5	2
"	"	"	"	"	"	"	61	39	"	"	35	13	"	"	28	10	"	0.2	3
"	"	"	"	"	"	"	60	40	"	"	39	22	"	"	16	14	"	0.1	4
"	June	"	"	"	47	53	44	56	17	28	14	28	3	19	8	24	-0.1	-0.2	2
"	"	"	"	"	"	"	56	44	"	"	14	16	"	"	6	13	"	-0.05	3
"	"	"	"	"	"	"	40	60	"	"	10	27	"	"	4	15		-0.15	4
"	Sept	"	"	"	78	22	68	32	64	13	55	13	55	9	45	19	0.5	0.25	2
"	"	"	"	"	"	"	86	14	"	"	70	22	"	"	58	2	"	0.7	3
"	"	"	"	"	"	"	76	24	"	"	63	6	"	"	56	11	"	0.85	4
"	Dec	"	"	"	88	12	62	38	62	6	35	10	41	3	26	7	0.4	0.15	2
"	"	"	"	"	"	"	67	33	"	"	41	13	"	"	28	8	"	0.2	3
"	"	"	"	"	"	"	52	48	"	"	26	28	"	"	15	10	"	-0.1	4

*MUWM - Monthly Medians Updated by Weighted Means

5. CONCLUSIONS

Briefly, the updating by the weighted means proposed by Rush and Gibbs[7] offers some improvement over the monthly medians in the prediction of f_oF_2 maps. Using a working uncertainty of 0.5 MHz for routine operations, it is found that under present circumstances of wide separation of ionosonde stations, the updating is not able to yield improvement of 0.5 MHz in f_oF_2 predictions, compared with the monthly medians. In the presentation of Rush and Gibbs,[7] f_oF_2, being referred to a single location, has only the one dimension of temporal extrapolation. In the discussion presented above of the error in the mapping of f_oF_2, where an additional dimension of spatial extrapolation is involved, the improvement gained in their approach, in temporal extrapolation, is offset by the error in spatial extrapolation in the mapping of f_oF_2. For the updating[7] to be operationally successful for the mapping of f_oF_2, a closer grid of ionosonde stations than the one presently available is needed.

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